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Collaborator Support: Identification of Fundamental Visual, Auditory, and Cognitive Requirements for Command and Control Environments

Dave E. Kancler
Nicole B. Arbuckle
Brian A. Taylor
University of Dayton Research Institute
Human Factors Group
300 College Park
Dayton OH 45496

Paul R. Havig
Scott M. Galster
Warfighter Interface Division
Human Effectiveness Directorate

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Air Force Research Laboratory
711th Human Performance Wing
Human Effectiveness Directorate
Warfighter Interface Division
Battlespace Visualization Branch
Wright-Patterson AFB OH 45433

NOTICE AND SIGNATURE PAGE

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FOR THE DIRECTOR

//signed//
Paul Havig, PhD
Program Manager
Battlespace Visualization Branch

//signed//
Daniel G. Goddard
Chief, Warfighter Interface Division
Human Effectiveness Directorate
711th Human Performance Wing
Air Force Research Laboratory

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Dave E. Kancler, Nicole B. Arbuckle, Brian A. Taylor*
Paul R. Havig, Scott M. Galster**

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Human Factors Group
300 College Park
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14. ABSTRACT
This effort involved two specific Targeted Investigations exploring the use of large-screen displays paired with desktop displays, typical in AOCs and other C2 environments. Specifically, two research areas were outlined: 1) the use of prompting to direct the operator’s attention to either the large-screen display or the small-screen display; and, 2) communication formats which could be used by an operator to collaborate with a second operator. The first research area evaluated the performance of participants in a Command and Control (C2) environment using auditory and visual stimuli as prompting cues to switch attention between a small screen and large screen display. Ten participants completed eight monitoring task sessions consisting of four different conditions; no cueing, auditory cueing, visual cueing, and combined auditory and visual cueing. Prompting, in any form, improved response times as compared to no prompt. No differences were found among prompt type. The second research area focused on three communication mediums which could be implemented in the C2 setting: spoken word, handwritten, and chat. Participants monitored a large display depicting the flights of three UAVs, while simultaneously tracking, on a separate smaller screen, the status of critical performance parameters of the UAVs. Results indicate a time and accuracy advantage for spoken word, with readback providing a speed-accuracy tradeoff . Participant preference was evenly divided in terms of communication technique and presence of readback.

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1.0 Summary

This project was conducted within the facilities at 711 HPW/RHC under contract FA8650-06-C-6755; program manager Dr. Paul Havig, 711 HPW/RHCP, 937-255-8737. Contractors participating in the data collection are University of Dayton Research Institute (UDRI) employees. Personnel from RHC and UDRI interacted with the subjects by providing training for C2 task, administering the test, and conducting outbrief tasks once the test was completed.

This effort involved two specific Targeted Investigations explored the use of large-screen displays paired with desktop displays, typical in AOCs and other C2 environments. Specifically, two research areas were outlined: 1) the use of prompting to direct the operator's attention to either the large-screen display or the small-screen display; and, 2) communication formats which could be used by an operator to collaborate with a second operator. The first research area evaluated the performance of participants in a Command and Control (C2) environment using auditory and visual stimuli as prompting cues to switch attention between a small screen and large screen display. Ten participants completed eight monitoring task sessions consisting of four different conditions; no cueing, auditory cueing, visual cueing, and combined auditory and visual cueing. Prompting, in any form, improved response times as compared to no prompt. No differences were found among prompt type. The second research area focused on three communication mediums which could be implemented in the C2 setting: spoken word, handwritten, and chat. Participants monitored a large display depicting the flights of three UAVs, while simultaneously tracking, on a separate smaller screen, the status of critical performance parameters of the UAVs. Results indicate a time and accuracy advantage for spoken word, with readback providing a speed-accuracy tradeoff. Participant preference was evenly divided in terms of communication technique and presence of readback.

2.0 Introduction

2.1 Scope

The scope of this effort was to address fundamental human factors issues associated with large shared displays and other collaboration technologies currently in use or proposed for use in collaborative command and control environments, such as Air Operations Centers (AOCs).

2.2 Background

The increasing pervasiveness of hardware and software systems has resulted in reduced costs associated with technologies for information display and sharing. While these savings allow more and more organizations to purchase advanced technologies, often acquisition and implementation decisions are made without full understanding of the potential benefits the technology offers. Although suites of collaborative technologies

have been acquired and integrated in many C2 environments, reports from the operational community are mixed with regard to the usability, usefulness, and effectiveness of these technologies.

The quantity of information available to operators today and information flow planned for network-centric warfare is staggering. Care must be taken to avoid unintended consequences such as information overload, attentional capture, change blindness, and decision biases associated with certain modes of information presentation. Solutions must consider improving shared situation awareness (SA) and increased speed of command. Effective use of collaborative technologies requires investigation of these types of fundamental human factors issues associated with their utility.

2.3 Tasks

The approach outlined for this effort involved two specific Targeted Investigations to address some of the issues above. Each Targeted Investigation explored the use of large-screen displays paired with desktop displays, typical in AOCs and other C2 environments. Specifically, two research areas were outlined: 1) the use of prompting to direct the operator's attention to either the large-screen display or the small-screen display; and, 2) communication formats which could be used by an operator to collaborate with a second operator.

Targeted Investigation 1, *Maintaining Vigilance with Auditory and Visual Cues in Command and Control Environments*, evaluated the performance of participants in a Command and Control (C2) environment using auditory and visual stimuli as prompting cues to switch attention between a small screen and large screen display. The use of spatial audio displays has been shown to reduce workload and improve target detection times[1]. The current design employed a two-screen model with multiple targets on each as well as a multimodal cueing strategy. Ten participants completed eight monitoring task sessions consisting of four different conditions; no cueing, auditory cueing, visual cueing, and combined auditory and visual cueing. Participants monitored a large display depicting the flights of three UAVs, while simultaneously tracking, on a separate smaller screen, the status of critical performance parameters of the UAVs. Reaction times and accuracy rates as well as perceived workload were compared across all four conditions. It was found that prompting, in any form, will improve response times as compared to no prompt. No differences were found among prompt type. The findings of this study apply to the C2 environment, and may also apply to other multi-task environments requiring monitoring of multiple visual displays.

Targeted Investigation 2, *The Effect of Communication Technique and Presence of Readback in Command and Control Environments*, focused on three communication mediums which could be implemented in the C2 setting. Efficient and effective communication between operators in a C2 environment is essential to mission success. Modern technology affords several communication options. The second Targeted Investigation evaluated three of these options: spoken word, handwritten, and electronic chat. Participants monitored a large display depicting the flights of three UAVs, while simultaneously tracking, on a separate smaller screen, the status of critical performance parameters of the UAVs. Using one of the three methods participants communicated key

events to a secondary operator. For half the trials, the secondary operator provided feedback (confirmation or request for clarification); for the other half, no readback was given. Performance times, accuracy, and subjective workload data was collected. User preference and familiarity with each form of communication was also evaluated. Initial results indicate a time and accuracy advantage for spoken word, with readback providing a speed-accuracy tradeoff. Participant preference was evenly divided in terms of communication technique and presence of readback.

Below is a detailed description of each Targeted Investigation.

3.0 Targeted Investigation 1: Maintaining Vigilance with Auditory and Visual Cues in Command and Control Environments.

3.1 The C2 Environment and Divided Attention

The term "Command and Control" (C2) can be used to describe a variety of applications requiring a centralized command center or facility. Typically, however, configuration of this facility involves a large screen display, or data wall, visible to multiple operators. Simultaneously, a given operator also has his or her own dedicated workstation. This setup, by design, will likely lead to tasks that require the operator's attention at the data wall, and other tasks that will require the operator's attention to his or her dedicated workstation. Divided attention in such a multitask environment can potentially lead to operator performance decrements with regard to one or both tasks.

Such decrements, in theory, could be mitigated by directing the operator's attention, when appropriate, to the appropriate display. Gunn et al.[2] discuss the advantages of sensory cueing strategies; that is, those which utilize a simple physical change to the stimuli in order to attract the operator's attention. Use of such cueing strategies has a demonstrated advantage over no cueing whatsoever, as well as cognitive cueing strategies, which require symbolic interpretations and manipulations (e.g., determining the sum of a number array before responding).

The use of spatial audio displays has been shown to reduce workload and improve target detection times[3]. Traditionally, such a paradigm utilizes a single display, containing single or multiple targets. The implications of such findings generally involve display design for combat vehicles, such as aircraft or tanks. The strength of such displays is their non-intrusive nature, which take advantage of a relatively free sensory channel (auditory) in order to convey information to the visually tasked operator. Such cross-modal time sharing can lead to improved performance[4], especially if the tasks in question are of a highly visual in nature[5]. In the C2 environment, when directing an operator's visual attention to the common or individual's display, an auditory cue might benefit the operator similarly. Basic research has shown an advantage in response times to auditory stimuli, as compared to visual sitimuli[6].

The objective of Targeted Investigation 1 was to evaluate the performance of an individual in a command and control (C2) environment, in which they were required to switch attention between a large screen display and a dedicated workstation. The large screen display contained general information depicting the flights of three UAVs, and the

dedicated workstation contained information specific to the participant depicting critical performance parameters of each UAV. The study compared various means to cue the user to direct attention between the two displays. Applications of the study involved the Command and Control (C2) environment, although the results may also be applied to combat vehicle display design.

3.2 Method

3.2.1 Participants

Ten adult participants (50 percent female) were sampled from the University of Dayton Research Institute and the Air Force Research Laboratory at Wright Patterson Air Force Base. All participation was voluntary. All participants had normal or corrected-to-normal vision.

3.2.2 Materials

3.2.2.1 Task Environment. A simulated task environment was created with a large, common display and one smaller workstation. A task set, representative of a C2 environment task, was developed requiring the participant to interact with the large screen display (LSD) and a dedicated small screen display (SSD). The C2 task environment was created using the Distributed Dynamic Decision-Making (DDD) software tool6. The task involved monitoring a simulation of three unmanned air vehicles (UAVs), with route and position depicted on the LSD, and gauges representing the status of specific aircraft information contained on the SSD.

3.2.2.2 Room. A 10’x12’ laboratory on the campus of Wright Patterson Air Force base was used to conduct the study. The LSD was affixed to the back wall of the laboratory and the SSD sat on a table approximately 6 feet in front of the LSD.

The SSD was a 17” desktop monitor supported by a MIcit Desktop running on Windows XP Professional which displayed the lower monitoring task as well as the visual cues (see Figure 1).

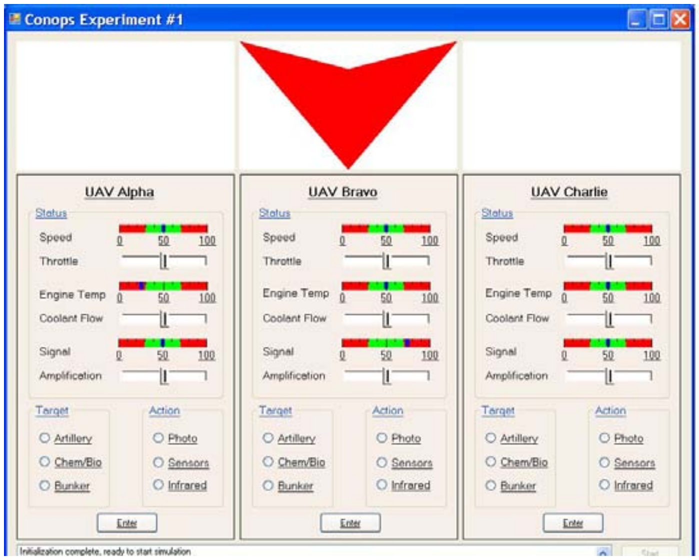

Figure 1: Small screen display; Study 1

A wall mounted (80” horizontal, 1280 x 1024 resolution) projection screen served as the LSD. Image was projected using an InFocus© projector from a Dell Dimension Desktop XPS running on Windows XP Professional. Figure 2 depicts the LSD.

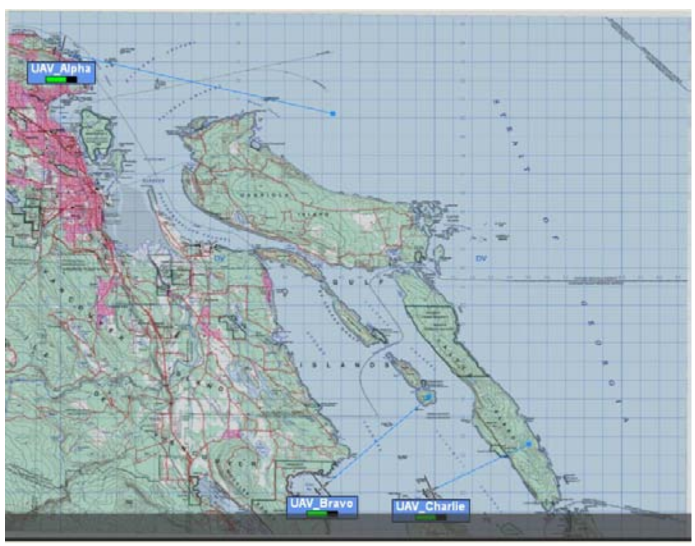

Figure 2: Large screen display; Study 1

3.2.2.3 Auditory Cues. Auditory tones played via Logitech stereo headphones cued an event. The tone ascended to indicate a LSD event and descended to indicate a SSD event. The tone played monaurally to the left ear to indicate an event on the left of the screen, monaurally to the right ear to indicate an event on the right of the screen, or binaurally to indicate an event on the middle of the appropriate screen.

3.2.2.4 Visual Cues. Visual cues of an event involved presentation of a red arrow (see Figure 1) via a display bar at the top of the SSD. Directionality was achieved by presenting the arrow in one of three positions within the display bar: left, center, or right

to indicate event location respectively. The cue pointed up to indicate an event on the LSD, or down to indicate an event on the SSD.

3.2.2.5 Subjective Measures. The researchers created a brief post procedure survey that included items that addressed the respondents' perceived performance for each type of event notification and preferred method of event notification. The NASA-TLX was administered electronically between each experimental session to collect participants' perceived workload.

3.2.3 Design

Participants completed one practice monitoring session and eight monitoring sessions which each lasted approximately six minutes in length. Depending on the condition a participant was either cued by auditory tones, visual signals, both or not at all. However, not every event within each condition was cued. This was included in the procedure to create the potential to test for participants' complacency with the task. Timing data was collected for each event as well as accuracy of response (correct, incorrect), cue presence (present, not present) and cue type (audio, visual, none, both).

3.2.4 Procedure

Each participant's session lasted approximately two hours including training. When they arrived, participants signed an informed consent and were verbally briefed on the task instructions.

Participants had two tasks which were to be performed simultaneously. The first task was to monitor a simulation of three UAV's represented on the LSD, and indicate when they encountered an event (artillery, chemBio, bunker). An event was indicated by a labeled icon which appeared on the LSD. Participants responded to the presence of an event by selecting the corresponding radio button on the SSD via the computers mouse.

The participants' second task was to monitor three gauges which indicated the status of three critical parameters (i.e., fuel remaining, signal strength, engine temperature) of the UAV's. When the critical parameters exceeded their optimal performance range, the gauge moved from a green area into a red area. Participants responded to the critical parameters by clicking on the indicator button on the SSD via the computers mouse when the indicator exceeded its limits.

After completing all eight sessions, participants were debriefed and asked to complete a post experiment survey.

3.3 Results

3.3.1 Reaction Time

A 2-way repeated-measures ANOVA was conducted to examine the effect of cue type and trial period on reaction time to an on-screen UAV incident. The within-subjects variables were cue type, with four levels (auditory cues, visual cues, simultaneous auditory and visual cues, and no cue), and two trial periods for each cue type. The results of the ANOVA are presented in Table 1, while Table 2 presents the means and standard deviations for these main effect groups. Alpha level .05 was used.

Table 1: ANOVA Summary Table for Reaction Time

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Stimulus	Sphericity Assumed	3793557.312	3	1264519.104	9.077	.000
	Greenhouse-Geisser	3793557.312	1.693	2241308.565	9.077	.004
	Huynh-Feldt	3793557.312	2.043	1857286.256	9.077	.002
	Lower-bound	3793557.312	1.000	3793557.312	9.077	.015
Error(Stimulus)	Sphericity Assumed	3761274.904	27	139306.478		
	Greenhouse-Geisser	3761274.904	15.233	246915.053		
	Huynh-Feldt	3761274.904	18.383	204609.014		
	Lower-bound	3761274.904	9.000	417919.434		
Trial	Sphericity Assumed	28875.169	1	28875.169	.119	.738
	Greenhouse-Geisser	28875.169	1.000	28875.169	.119	.738
	Huynh-Feldt	28875.169	1.000	28875.169	.119	.738
	Lower-bound	28875.169	1.000	28875.169	.119	.738
Error(Trial)	Sphericity Assumed	2177001.263	9	241889.029		
	Greenhouse-Geisser	2177001.263	9.000	241889.029		
	Huynh-Feldt	2177001.263	9.000	241889.029		
	Lower-bound	2177001.263	9.000	241889.029		
Stimulus * Trial	Sphericity Assumed	372156.613	3	124052.204	1.037	.392
	Greenhouse-Geisser	372156.613	2.334	159428.945	1.037	.382
	Huynh-Feldt	372156.613	3.000	124052.204	1.037	.392
	Lower-bound	372156.613	1.000	372156.613	1.037	.335
Error(Stimulus*Trial)	Sphericity Assumed	3231374.727	27	119680.545		
	Greenhouse-Geisser	3231374.727	21.009	153810.593		
	Huynh-Feldt	3231374.727	27.000	119680.545		
	Lower-bound	3231374.727	9.000	359041.636		

Due to a significant violation of the assumption of sphericity (p=.041), the Greenhouse-Geiser test was used to adjust the degrees of freedom. A significant main effect for cue type was found, $F(1.693, 15.233) = 9.077$, $p < 0.01$. Participants responded significantly slower in the "no cue" condition than any other condition. There were no significant differences in reaction time between the other stimulus conditions. Additionally, there was not a significant main effect of trial period, $F(1, 9) = .119$, $p = .738$, nor the interaction of cue type and trial period, $F(2.334, 21.009) = 1.037$, $p = .382$.

Table 2: Response Times in Seconds

Factor	M	SD
Auditory	26.359	3.798
Visual	27.837	4.719
Combined	27.487	4.864
No Cue	32.096	7.303
Trial 1	28.635	5.408
Trial 2	28.255	5.982

Each cued condition contained both cued and non-cued events to ensure participant vigilance. Therefore, a separate analysis was conducted using only data collected from each of the "true" (cued) events (i.e., non-cued events in the cued condition were excluded from the analysis).

3.3.1.1 "True" Only Events. A 2-way repeated-measures ANOVA examining the effect of "true" cues and trial period on reaction time was conducted. Table 3 presents the means and standard deviations for the main effect groups. Alpha level .05 was used. A significant main effect for cue type was found, $F(3, 27) = 13.577$, $p < 0.001$. Participants responded significantly slower in the "no cue" condition than any other condition. There was not a significant main effect of trial period, $F(1, 9) = .363$, $p = .562$, nor the interaction of cue type and trial period, $F(3, 27) = 1.611$, $p = .210$.

Table 3: "True" only reaction time means and standard deviations

Factor	M	SD
Auditory	25.193	4.571
Visual	26.733	4.883
Combined	26.105	4.560
No Cue	32.096	7.303
Trial 1	27.727	5.937
Trial 2	27.094	6.172

3.3.2 Workload

A 2-way repeated-measures ANOVA was conducted to examine the effect of cue type and trial period on subjective workload. Table 4 presents the means and standard deviations for these main effect groups. Alpha level .05 was used. Due to a significant violation of the assumption of sphericity (p=.034), the Greenhouse-Geiser test was used to adjust the degrees of freedom. There was no significant main effect for cue type, $F(1.625, 14.626) = .405$, $p = .633$, trial period, $F(1, 9) = 1.688$, $p = .226$, or the interaction of cue type and trial period, $F(2.285, 20.562) = .392$, $p = .760$.

Table 4: Workload means and standard deviations

Factor	M	SD
Auditory	46.533	20.837
Visual	46.467	19.660
Combined	49.683	20.930
No Cue	47.067	21.564
Trial 1	48.300	22.734
Trial 2	46.575	20.325

3.3.3 Rank Preference and Perceived Performance

A within-subjects comparison of rank orders was performed on the cue type using the Friedman test on both preference and perceived performance. Alpha level .05 was used. The Friedman test significantly placed the cue types in order of preference by Combined (1.7), Visual (2.2), Auditory (2.3), and None (3.8) (Friedman $X^2 = 14.76$, $p = .002$). Additionally, the Friedman test significantly placed the cue types in order of perceived performance by Combined (2.0), Auditory (2.1), Visual (2.2), and None (3.7) (Friedman $X^2 = 11.64$, $p = .009$). Multiple comparisons revealed that No Cue was preferred significantly less than Audio ($p = .012$), Visual ($p = .004$), and Both ($p = .010$). Also, multiple comparisons revealed that performance with no prompt was perceived as less than Audio ($p = .024$), Visual ($p = .004$), and Both ($p = .017$). Multiple comparisons revealed no other significant differences in rankings in either preference or liking.

3.3.4 Errors

No statistical analysis was conducted on error data, as participants across all four conditions did not make enough errors for an accurate analysis.

3.4 Discussion

The general result that any type of prompt is better than no prompt was expected. This pattern held true in terms of performance times, perceived performance, and preference. However, the lack of statistical evidence favoring one prompting strategy over another was unexpected, especially in light of other research in this area[6]. This lack of evidence held true across all measures, including response time and preference. Several reasons may account for this non-finding and are discussed below.

Participant preference indicated that some type of prompting was preferred over no prompting. However, no specific prompt strategy was preferred. This may be due to differing learning styles among the participant pool[8]. A standard learning style survey was not implemented as part of Targeted Investigation 1; however, conflicting post test

feedback regarding preferred prompt technique provides some anecdotal evidence. For example, a majority of participants preferred the combination of audio and visual prompts. The reason given for this preference was to receive "as much prompting as possible." However, to others, the combination of audio and visual prompting was excessive. Two participants stated that they preferred audio, as it did not interfere with the visual search task. An additional participant preferred visual prompting only; the reason given that the auditory prompt, which resembled a siren, increased the participant's stress level. With such a disparity of reasons given for preference ranking, future research should involve implementing a learning style test, such as the VARK[9].

Another non-significant finding was that auditory prompting showed no advantage over other prompt formats. The intent of using auditory prompting during a visual task is to take advantage of a second, unused perceptual channel. While this finding may initially seem surprising, Wickens[3] states that, if the physical distance between the competing visual elements (e.g., visual task and visual prompt) is not great enough, advantage of auditory is not realized. From the participant's point of view, the visual prompt was strategically positioned to minimize visual orienting. An unintended consequence of this strategy may have been to minimize the need for a secondary channel (e.g., audio) in terms of prompting.

Finally, it is recommended that future studies increase the vigilance requirement associated with the experimental task. The sessions in Targeted Investigation 1 lasted approximately 18 minutes, with an even occurring every 20 seconds. While this arrangement generated a large number of data points in a short time span, the need for a longer period of data collection may exist. The non-significant analysis of workload scores may have been due to a lack of vigilance required for each session. Longer data collection sessions may also help to illustrate potential long-term benefits of a given prompt strategy over another. In general, future research could space events more randomly over a larger period of time.

The results of Targeted Investigation 1 indicate that the provision of some form of prompting will benefit the participant. However, objective and subjective results to not point to a specific format as preferred. In the meantime, designers should consider multiple formats to allow for individual user preferences. Additionally, future research should include longer test sessions, to create a true vigilance-oriented task. Also, the impact of participant learning style on prompt preference should be investigated, to more effectively determine the need for multiple prompting strategies.

4.0 Targeted Investigation 2: The Effect of Communication Technique and Presence of Readback in Command and Control Environments

4.1 The C2 Environment and Team Communication

"Command and Control" (C2) facilities are typically configured with a large-screen display, or data wall, visible to multiple operators. Simultaneously, a given operator also has his or her own dedicated workstation for work activities specific to that user. In such a setting, communication between operators may take several forms, the basis for which may involve technology, personal preference, or both. The most effective form of

communication, however, may not be the most preferred. Nielson and Mack[10] indicate that users, even when given proof that their performance is better when using a given technology, will not use that technology if they do not prefer it.

Another issue in determining an effective communication method is that of fostering team cohesiveness. For example, prior studies indicate that trust is generally slow to develop and particularly fragile when team members do not get an opportunity to interact face-to-face[10,11]. Therefore, the selection and implementation of a communication technique must balance performance and user acceptance, ideally retaining some factors associated with face-to-face interactions.

Three communication techniques with potential to be utilized in the C2 setting are spoken word, written messages, and the use of electronic chat software. Each technique offers advantages and disadvantages. For example, while spoken word is likely to be most familiar to the greatest number of users, it can be intrusive to other operators in the task environment. As well, it appears that documentation or capture of spoken communication can be cumbersome. Handwritten messages and chat are both visual mediums, providing a smoother transcription process than spoken word. This is especially true in the case of chat, where an electronic text file can be generated literally as a session progresses. However, some users may not be comfortable with the novelty of chat software. Other tradeoffs apply to handwritten communication, such as legibility and the logistics of delivery.

Because a collaborative environment involves at least two individuals, the behavior of the second individual can directly impact the overall quality of communication. The concept of read-back, or offering a confirmation or request for clarification, is standard procedure in settings such as aviation[13] and medical situations[14]. Thus, a second factor that may influence the effectiveness of a given communication technique is the presence or absence of return communication from the second individual.

Given the array of capabilities and options provided by today's technology, a multifaceted investigation was developed to evaluate spoken word, written messages, and the use of chat software as communication techniques in the C2 setting. The impact of "read-back" was also evaluated. The intent of this variable was to not necessarily evaluate whether performance increased, but rather subjective preference associated with perceived read-back performance for a given communication technique.

4.2 Method

4.2.1 Design

The experimental design was a 2x3 within subjects design. The two independent variables were Readback (Present, Absent), and Communication Type (Chat, Spoken Word, Written).

4.2.2 Participants

Ten adult participants (50 percent female) were sampled from the University of Dayton Research Institute and the Air Force Research Laboratory at Wright Patterson Air Force Base. All participation was voluntary. All participants had normal or corrected-to-normal vision.

4.2.3 Materials

4.2.3.1 Task Environment. A simulated C2 setting was developed for this study. This setting included a large, common display and one smaller workstation for individual use. The task set required the participant to interact with the large screen display (LSD) and a dedicated small screen display (SSD). The C2 task environment was created using the Distributed Dynamic Decision-Making (DDD) software tool. The task involved monitoring a simulation of three unmanned air vehicles (UAVs), with route and position depicted on the LSD, and gauges representing the status of specific aircraft information contained on the SSD.

4.2.3.2 Room. A 10'x12' laboratory at Wright Patterson Air Force base was used to conduct the study. The LSD was affixed to the back wall of the laboratory and the SSD sat on a table approximately 6 feet in front of the LSD.

The SSD was a 17" desktop monitor supported by a MIcit Desktop running on Windows XP Professional which displayed the lower monitoring task (see Figure 3).

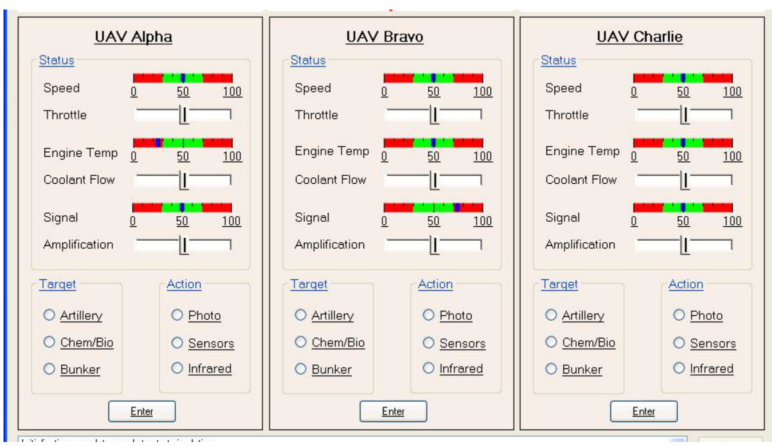

Figure 3: Small screen display; Study 2

A wall mounted (80" horizontal, 1280 x 1024 resolution) projection screen served as the LSD. Image was projected using an InFocus© projector from a Dell Dimension Desktop XPS running on Windows XP Professional. Figure 4 depicts the LSD.

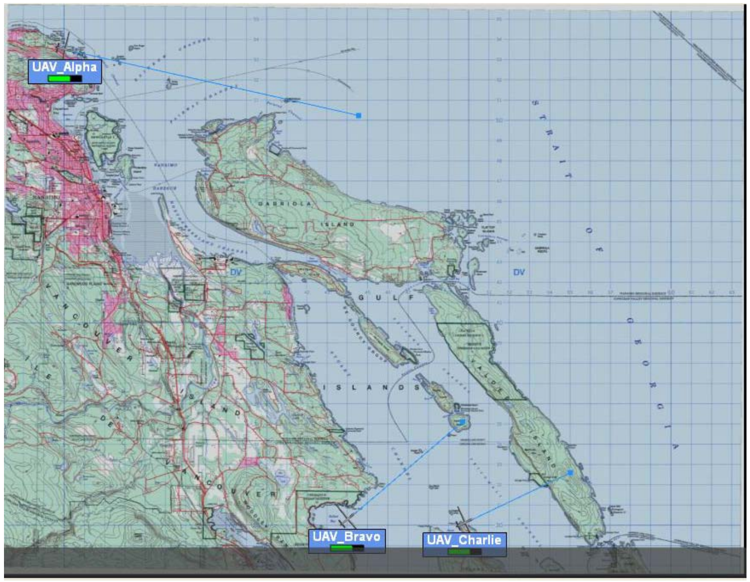

Figure 4: Large screen display; Study 2

4.2.3.3 Subjective Measures. The NASA-TLX was administered electronically between each experimental session to collect participants' subjective workload. A one-page, post-test survey was administered to collect preference rankings, perceived performance, and comfort level with each communication technique.

4.2.4 Procedure

The experiment team consisted of two persons: The Experimenter and the Secondary Observer. The Experimenter was responsible for briefing the participant, providing instruction before each session, and administering the NASA TLX after each condition. The Secondary Observer's role was to receive communication from the participant during a session, and depending on the condition, provide feedback in the form of "reading back" the participant's response and either: 1) acknowledging accuracy, or 2) requesting a correction. Participation lasted approximately 90 minutes, including training.

Participants completed a practice session for each communication type. Within each communication type, a total of twenty communication events were completed. For a given participant, the first ten events were readback conditions, and the remaining ten were not (or vice versa). Participants were trained on the proper procedure for responding to the event, communicating using the applicable method, and (when appropriate) responding to readback from the Secondary Observer. Order of communication type was controlled via Latin square.

Participants conducted two concurrent tasks. The first task was to monitor the simulated flight tracks of three UAVs on the large screen display; the second task was to monitor three status windows on the small screen display, which indicated the status of three critical UAV system parameters (i.e., fuel remaining, signal strength, engine temperature) of the UAVs. Both tasks had the potential for the occurrence of an "event." A large screen event, or Target Event, was an encounter with a target of opportunity (artillery,

chemBio, bunker). A small screen event, or Status Event, was an out-of-limits reading on one of the key system status parameters.

Upon recognizing the occurrence of an event, the participant communicated key, predefined aspects to the experimenter. The intent was to require information similar to that on a K02.33 CAS 9 Line form, which is a standardized checklist used to document and communicate key target parameters in the battlespace environment. For a Status Event, these parameters were: Event Type, UAV Name, Location, Time (mm:ss), Malfunction, Level (High/Low), and Corrective Action. For a Target Event, these parameters were: Event Type, UAV Name, Target Name, Location X, Location Y, Altitude, and Time (mm:ss). A list of these parameters was given to the participant for use as a script to follow for communicating to the Secondary Observer.

During a given session, participants communicated to the Secondary Observer in one of three ways: spoken word, handwritten, or electronically via chat software. Participants were briefed and trained before each session on the communication technique to be used, and were given a chance to practice. Once comfortable with the assigned communication technique, the Experimenter started the trial.

Spoken word required the participant to orally communicate to the Secondary Observer each key parameter. In the handwritten condition, the participant completed a 4” x 4” paper form containing each of the parameters in the same order as the script. The chat condition used Jabber™ as the chat software; the participant typed the parameters, one line per parameter, to the Secondary Observer.

Participants communicated a total of twenty events using each technique. For half of each, the Secondary Observer provided feedback to the participant, in the form of a “readback” confirmation (“[parameter] OK”) or request to recheck for accuracy (“[parameter] Recheck”).

4.3 Results

4.3.1 Response Time

A 2-way repeated-measures ANOVA was conducted to examine the effect of Readback and Communication Type on the time taken to complete the predetermined communication parameters. The within-subjects variables were Readback, with two levels (Readback Present and Readback Absent), and Communication Type (Spoken Word, Handwritten, and Chat Software). Alpha level .05 was used. Table 6 presents the ANOVA Summary Table for this analysis while Table 5 depicts the means and standard deviations.

As expected, a significant main effect for Readback was found, $F(1, 9) = 110.503$, $p < 0.001$. Participants took significantly longer to complete the task in the Readback Present condition than the Readback Absent condition. A significant main effect for Communication Type was also found, $F(2, 18) = 58.275$, $p < 0.001$. Subsequent pairwise comparisons revealed that participants took significantly longer to complete the task in the Chat Software condition than both the Handwritten condition ($p = .036$) and the

Spoken Word condition ($p < .001$), and took significantly longer to complete the Handwritten condition than the Spoken Word condition ($p < .001$).

Table 5: Response time in seconds

Factor	M	SD
Readback Present	46.801	13.954
Readback Absent	27.094	7.321
Spoken Word	25.528	6.540
Handwritten	40.119	13.467
Chat Software	45.195	15.556

Table 6: ANOVA Summary Table for Response Time

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Medium	Sphericity Assumed	4169637846	2	2084818923	58.275	.000
	Greenhouse-Geisser	4169637846	1.617	2578032978	58.275	.000
	Huynh-Feldt	4169637846	1.920	2171828583	58.275	.000
	Lower-bound	4169637846	1.000	4169637846	58.275	.000
Error(Medium)	Sphericity Assumed	643954548	18	35775252.68		
	Greenhouse-Geisser	643954548	14.556	44238749.09		
	Huynh-Feldt	643954548	17.279	37268328.43		
	Lower-bound	643954548	9.000	71550505.37		
Condition	Sphericity Assumed	5825214796	1	5825214796	110.503	.000
	Greenhouse-Geisser	5825214796	1.000	5825214796	110.503	.000
	Huynh-Feldt	5825214796	1.000	5825214796	110.503	.000
	Lower-bound	5825214796	1.000	5825214796	110.503	.000
Error(Condition)	Sphericity Assumed	474440405	9	52715600.60		
	Greenhouse-Geisser	474440405	9.000	52715600.60		
	Huynh-Feldt	474440405	9.000	52715600.60		
	Lower-bound	474440405	9.000	52715600.60		
Medium * Condition	Sphericity Assumed	564471115	2	282235557.4	18.752	.000
	Greenhouse-Geisser	564471115	1.287	438598541.5	18.752	.001
	Huynh-Feldt	564471115	1.409	400535416.0	18.752	.000
	Lower-bound	564471115	1.000	564471114.8	18.752	.002
Error(Medium*Condition)	Sphericity Assumed	270924216	18	15051345.32		
	Greenhouse-Geisser	270924216	11.583	23390029.82		
	Huynh-Feldt	270924216	12.684	21360160.69		
	Lower-bound	270924216	9.000	30102690.64		

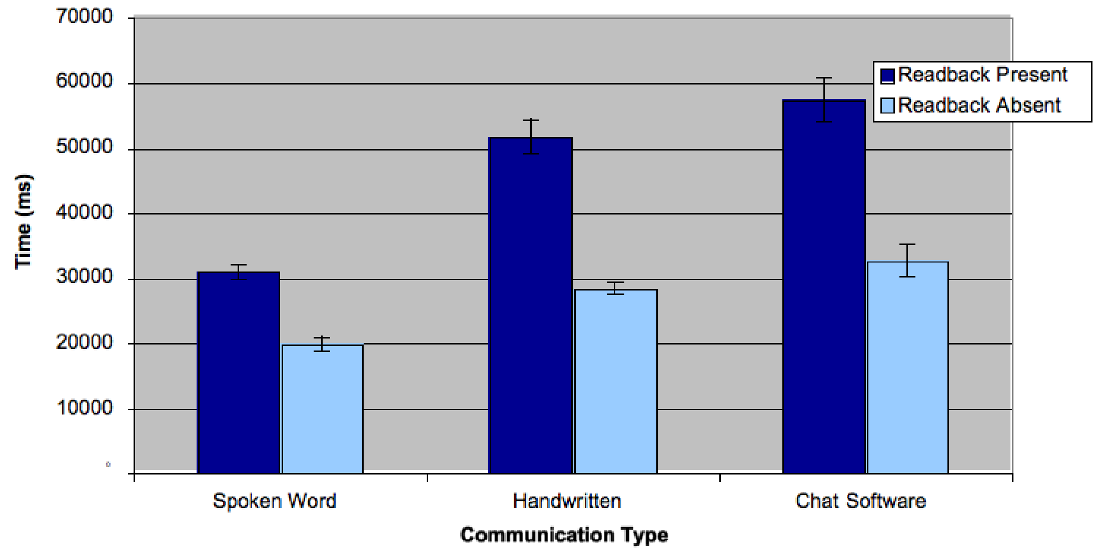

Figure 5: Mean time to complete task; communication type x readback presence

The interaction of Readback and Communication Type was significant, $F(2, 18) = 18.752$, $p < .001$, as shown in Figure 5. Simple effects were analyzed to further examine the effect of Readback on each Communication Type. Table 7 presents the means and standard deviations. Paired t-Tests revealed that the effect was strongest for Spoken Word ($t(6) = 12.131$, $p < .001$), moderate for Handwritten ($t(6) = 8.002$), and weakest for Chat Software ($t(6) = 6.406$, $p < .001$).

Table 7: Response time in seconds

Factor	M	SD
Spoken Word-Readback Present	32.080	3.481
Spoken Word-Readback Absent	20.994	3.018
Handwritten-Readback Present	54.643	8.508
Handwritten-Readback Absent	28.337	3.495
Chat Software-Readback Present	57.165	12.198
Chat Software-Readback Absent	30.726	8.047

4.3.2 Workload

A 2-way repeated-measures ANOVA was conducted to examine the effect of Readback and Communication Type on Overall subjective workload. Table 8 presents the ANOVA summary table for this analysis while Table 9 presents means and standard deviations for these groups.

There was no significant main effect for Readback, F(1, 9) = .602, p = .458, Communication Type, F(2, 18) = 1.025, p = .379, or the interaction of Readback and Communication Type, F(2, 18) = 1.274, p = .304.

Table 8: ANOVA Summary Table for Workload

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Stimulus	Sphericity Assumed	138.827	3	46.276	.405	.751
	Greenhouse-Geisser	138.827	1.625	85.428	.405	.633
	Huynh-Feldt	138.827	1.932	71.845	.405	.666
	Lower-bound	138.827	1.000	138.827	.405	.540
Error(Stimulus)	Sphericity Assumed	3086.709	27	114.323		
	Greenhouse-Geisser	3086.709	14.626	211.048		
	Huynh-Feldt	3086.709	17.391	177.490		
	Lower-bound	3086.709	9.000	342.968		
Trial	Sphericity Assumed	59.513	1	59.513	1.688	.226
	Greenhouse-Geisser	59.513	1.000	59.513	1.688	.226
	Huynh-Feldt	59.513	1.000	59.513	1.688	.226
	Lower-bound	59.513	1.000	59.513	1.688	.226
Error(Trial)	Sphericity Assumed	317.334	9	35.259		
	Greenhouse-Geisser	317.334	9.000	35.259		
	Huynh-Feldt	317.334	9.000	35.259		
	Lower-bound	317.334	9.000	35.259		
Stimulus * Trial	Sphericity Assumed	40.782	3	13.594	.392	.760
	Greenhouse-Geisser	40.782	2.285	17.851	.392	.707
	Huynh-Feldt	40.782	3.000	13.594	.392	.760
	Lower-bound	40.782	1.000	40.782	.392	.547
Error(Stimulus*Trial)	Sphericity Assumed	936.983	27	34.703		
	Greenhouse-Geisser	936.983	20.562	45.570		
	Huynh-Feldt	936.983	27.000	34.703		
	Lower-bound	936.983	9.000	104.109		

In addition to Overall Workload, 2-way repeated-measure ANOVA's were conducted to examine the effect of Readback and Communication Type on the individual workload subscales (Physical Demands, Mental Demands, Temporal Demands, Own Performance, Effort, and Frustration).

Table 9: Workload means and standard deviations

Factor	M	SD
Readback Present	46.045	17.070
Readback Absent	43.344	16.737
Spoken Word	42.917	15.627
Handwritten	41.650	18.396
Chat Software	49.517	16.059

A significant main effect of Readback on Physical Demands, $F(1, 9) = 3.919$, $p = .046$, was observed; Physical Demands were greater for the Readback Present condition than for the Readback Absent condition. No other effects were significant at alpha level .05.

4.3.3 Subjective Rankings

Participants were asked to rank order the six levels of Readback by Communication Type based on subjective time performance, preferred condition, and perceived value of Readback for each communication type. A within-subjects comparison of these rank orders was performed using the Friedman test.

4.3.3.1 Subjective Performance. The Friedman test was significant (Friedman $X^2 = 18.114$, $p = .001$). The six levels in order of perceived performance are listed below, with their average placement (1=most, 6=least):

- Spoken Word-Readback Absent (1.9),
- Handwritten-Readback Absent (2.8),
- Spoken Word-Readback Present (3.3),
- Chat Software-Readback Absent (3.5),
- Handwritten-Readback Present (4.5),
- Chat Software-Readback Present (5.0),

Paired comparisons revealed the following three groupings regarding perceived performance:

1. Spoken Word-Readback Absent ranked significantly higher than Chat Software-Readback Absent ($p = .047$), Handwritten-Readback Present ($p = .027$), and Chat Software-Readback Present ($p = .012$).
2. Handwritten-Readback Absent ranked significantly higher than Handwritten-Readback Present ($p = .021$) and Chat Software-Readback Present ($p = .002$).
3. Chat Software-Readback Absent ranked significantly higher than Chat Software-Readback Present ($p = .025$).

4.3.3.2 Preference. The Friedman test was non-significant, but approached significance (Friedman $X^2 = 9.371$, $p = .090$). The six levels in order of preference are listed below, with their average placement (1=most, 6=least):

- Spoken Word-Readback Present (2.5),
- Spoken Word-Readback Absent (2.7),
- Handwritten-Readback Absent (3.5),
- Chat Software-Readback Absent (3.7),
- Handwritten-Readback Present (3.9), and
- Chat Software-Readback Present (4.7).

4.3.3.3 Perceived Value of Readback. The Friedman test was non-significant for rank order based on Perceived Value of Readback (Friedman $X^2 = 3.200$, $p = .222$).

4.3.4 Errors.

Errors were categorized as one of two types: Critical and Non-Critical. Critical errors were those which would compromise the effectiveness of communication. The following errors fell under this category: any incorrect information given, any omission of checklist information, and out of sequence checklist information. Conversely, Non-Critical errors were identified as mistakes made which would not compromise information integrity.

4.3.4.1 Critical Errors. A 2-way repeated-measures ANOVA was conducted to examine the effect of Readback and Communication Type on the number of critical errors observed during communication. The within-subjects variables were Readback, with two levels (Readback Present and Readback Absent), and Communication Type (Spoken Word, Handwritten, and Chat Software).

Table 10 provides the summary results for the ANOVA. No effect was observed for Communication Type F(2, 18) = 1.33, p = .322 or Readback F(1, 9) = .47, p = .509 on critical errors. The interaction of Readback x Communication Type approached (but did not reach) significance at the P=.05 level [F(1, 9) = 3.86, p = .067].

Table 10: ANOVA Summary Table for Critical Errors

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Medium	Sphericity Assumed	.433	2	.217	1.206	.322
	Greenhouse-Geisser	.433	1.378	.315	1.206	.313
	Huynh-Feldt	.433	1.545	.280	1.206	.316
	Lower-bound	.433	1.000	.433	1.206	.301
Error(Medium)	Sphericity Assumed	3.233	18	.180		
	Greenhouse-Geisser	3.233	12.400	.261		
	Huynh-Feldt	3.233	13.907	.232		
	Lower-bound	3.233	9.000	.359		
Readback	Sphericity Assumed	.067	1	.067	.474	.509
	Greenhouse-Geisser	.067	1.000	.067	.474	.509
	Huynh-Feldt	.067	1.000	.067	.474	.509
	Lower-bound	.067	1.000	.067	.474	.509
Error(Readback)	Sphericity Assumed	1.267	9	.141		
	Greenhouse-Geisser	1.267	9.000	.141		
	Huynh-Feldt	1.267	9.000	.141		
	Lower-bound	1.267	9.000	.141		
Medium * Readback	Sphericity Assumed	.433	2	.217	3.162	.067
	Greenhouse-Geisser	.433	1.931	.224	3.162	.069
	Huynh-Feldt	.433	2.000	.217	3.162	.067
	Lower-bound	.433	1.000	.433	3.162	.109
Error(Medium*Readback)	Sphericity Assumed	1.233	18	.069		
	Greenhouse-Geisser	1.233	17.378	.071		
	Huynh-Feldt	1.233	18.000	.069		
	Lower-bound	1.233	9.000	.137		

4.3.4.2 Non Critical Errors. A 2-way repeated-measures ANOVA was conducted to examine the effect of Readback and Communication Type on the number of non-critical errors observed during communication. The within-subjects variables were Readback, with two levels (Present and Absent), and Communication Type (Spoken Word, Handwritten, and Chat Software).

Table 11: ANOVA Summary Table for Non-Critical Errors

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Medium	Sphericity Assumed	3.900	2	1.950	2.325	.126
	Greenhouse-Geisser	3.900	1.526	2.555	2.325	.143
	Huynh-Feldt	3.900	1.775	2.197	2.325	.134
	Lower-bound	3.900	1.000	3.900	2.325	.162
Error(Medium)	Sphericity Assumed	15.100	18	.839		
	Greenhouse-Geisser	15.100	13.738	1.099		
	Huynh-Feldt	15.100	15.973	.945		
	Lower-bound	15.100	9.000	1.678		
Readback	Sphericity Assumed	3.267	1	3.267	12.250	.007
	Greenhouse-Geisser	3.267	1.000	3.267	12.250	.007
	Huynh-Feldt	3.267	1.000	3.267	12.250	.007
	Lower-bound	3.267	1.000	3.267	12.250	.007
Error(Readback)	Sphericity Assumed	2.400	9	.267		
	Greenhouse-Geisser	2.400	9.000	.267		
	Huynh-Feldt	2.400	9.000	.267		
	Lower-bound	2.400	9.000	.267		
Medium * Readback	Sphericity Assumed	2.033	2	1.017	4.256	.031
	Greenhouse-Geisser	2.033	1.839	1.106	4.256	.035
	Huynh-Feldt	2.033	2.000	1.017	4.256	.031
	Lower-bound	2.033	1.000	2.033	4.256	.069
Error(Medium*Readback)	Sphericity Assumed	4.300	18	.239		
	Greenhouse-Geisser	4.300	16.547	.260		
	Huynh-Feldt	4.300	18.000	.239		
	Lower-bound	4.300	9.000	.478		

The main effect of Communication Type was not significant $F(2, 18) = 5.49$, $p = .126$. The main effect of Readback was significant $F(1, 9) = 12.25$, $p = .007$; for this main effect, Readback presence resulted in significantly fewer non-critical errors.

Figure 6 illustrates the significant interaction of Readback x Communication Type [$F(2, 18) = 1.02$, $p = .031$]. Analysis of simple effects revealed that Readback presence increased non-critical errors in the Chat condition [$t(9) = 3.88$, $p = .004$]; however, Readback had no effect on non-critical errors in the Handwritten condition [$t(9) = 0.0$, $p = 1.000$] or the Spoken Word condition $t(9) = 2.24$, $p = .052$].

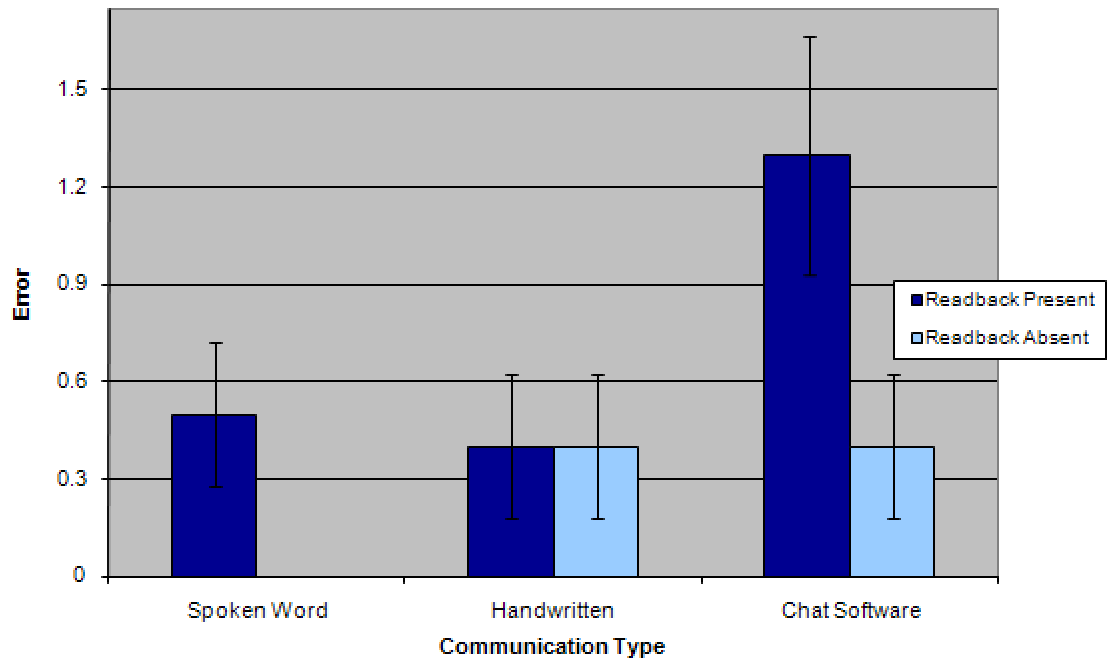

Figure 6: The interaction of Communication Type x Readback Presence on non-critical errors

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4.4 Discussion

The results of Target Investigation 2 indicate that Spoken Word offers a performance advantage and is preferred over Handwritten and Chat formats. Absence of Readback offers faster response times and was preferred over the presence of Readback, even with potential error correction offered by a "second set of eyes." Finally the non-significant findings involving critical errors and the significant interaction involving non-critical errors defy an expected speed-accuracy tradeoff. These findings are discussed below.

The time advantage of Spoken Word over either Handwritten or Chat fits with the concept that speaking is a more universally understood medium of communication. Furthermore, when compared to chat and writing in the present study, verbal communication seemed to occur in a smoother, more familiar manner. That is, participants seemed to fall into a pattern of speaking which they adopted throughout the study. In contrast, chat and handwritten required completion of a line-item before communication took place, which seemed to somewhat disrupt the timing and flow of information exchange, and thus added to the time advantage of speaking as a communication medium.

When combining the above mentioned time results with the results regarding preference, it seems an easy decision that speaking, without the involvement of a second person, should be considered as a primary communication technique. This is especially true if

time is a high priority. However, when weighing other factors (e.g., documentation techniques and conditions of the overall work environment), voice may not be the preferred option. For example, the Targeted Investigation 2 environment was controlled, with no more than three individuals (including the participant) present at a given time. Each piece of information was conveyed in a controlled setting, such that information could not readily be lost. In an operational setting, with a potentially aurally saturated work environment, speaking performance may become compromised. Similarly, handwriting may become less legible during times of high temporal demand or overall workload levels. In these cases, mediums other than spoken word may actually offer an overall advantage.

While the findings involving response time seem fairly straightforward, the findings involving errors were, at least at first glance, not. The intent of the Readback requirement was to offer a tradeoff between speed and accuracy, likely realizing a decrease in errors while sacrificing overall response times. Thus, the main effect of Readback on response time is not surprising -- more time is generally needed if two operators are required to communicate. However, greater evidence of a speed-accuracy tradeoff was expected, on two fronts. First, the Secondary Operator's responses provided by the Readback present condition was expected to reduce critical errors. This effect was not observed. Second, in the Chat condition, the ability to easily review one's input before submitting was anticipated to generate slower, but more accurate overall responses with regards to both critical and non-critical errors. While the increase in Chat time occurred, the reduction in critical errors did not significantly lessen. Furthermore, for non-critical errors, the significant interaction of Readback x Communication Type illustrated an *increase* in the number of non-critical errors, when Readback was present. Thus, a strategy intended to decrease errors actually seemed to have the opposite effect.

To begin to understand this seemingly conflicting finding, one must investigate the differences in nature between critical and non-critical errors, and the role of the Secondary Operator in addressing them. To begin, the Readback present condition was set up to catch critical errors – that is, errors involving mission-essential data. As mentioned above, this finding did not occur. On the other hand, non-critical errors were not essential to mission success. These errors involved the more subtle aspects of accuracy, such as communication miscues or violations of protocol. The secondary Operator had little say as to whether non-critical errors were made, and was focused on the correctness of the data. Thus, by nature, the Readback condition was more likely to catch and correct critical errors.

To further address the seemingly unusual non-critical error findings, the characteristics of medium by which communication took place must also be considered. The significant interaction of Readback x Communication Type illustrates that, depending on the communication medium, such errors may increase as the amount of communication increases. Specifically, Chat's relatively recent emergence as a communication technique may have contributed to this finding; an overall protocol is not established, and the medium itself is susceptible to mistakes such as inadvertent keystrokes and typographical errors. These mistakes are easily made without notice. Moreover, the chat medium required the operator to divide attention between at least two (and depending on typing style, three) disparately located information sources: 1) target information, 2) chat

window, and 3) keyboard. By contrast, the Handwritten and Spoken Word conditions offered the advantages of familiarity and, for the Handwritten condition, the option to completely review one's work before submitting. This may have led to identical non-critical error findings in the Handwritten condition. It should be noted that this strategic difference for the Handwritten protocol was seen by the researchers as more practical in implementing Readback for written form-filling in a C2 environment. As such, overall Handwritten completion times may also have been shortened, as compared to a protocol more parallel to that of Chat and Spoken Word, which would have required the handing back and forth of a written checklist after completing each individual line item.

In summary, by its nature, the presence of a Readback requirement likely generated the potential for an increase in non-critical errors. Such an increase was observed in the current study, specifically when using a relatively new technology – in the case of the present study, chat. Future C2 research should further address these issues, with an emphasis on what is practical in the operational C2 setting. Designers, as well, should interpret these findings with the consideration that non-critical errors may be manageable, depending on the communication technology and the established communication protocol. The nature and impact of such errors may be an acceptable design consideration within the larger picture of communication documentation, logistics, and work environment.

5.0 Conclusion

The two studies conducted for this project sought to address situations in the C2 setting in which an operator would be required to divide attention. The specific situations addressed were: 1) how the operator's attention could be directed to relevant or critical tasking information; and, 2) techniques to enable the operator to communicate information about those critical events to a second individual. The combined findings from both studies depict a pattern of, which supports better operator performance and greater operator preference, based on increased familiarity with technique and technology. Such an issue must be considered by future researchers, as well as designers, when considering whether to implement new technologies in an environment with established practices. The trade-offs offered by such implementations will be an important factor; for example, the ability to quickly and accurately archive chat sessions versus slower response times and lower user preference rankings as compared to speaking.

In conclusion, three important factors must be considered when prioritizing collaborative medium: the technology, the environment, and the user. Both Targeted Investigations focused primarily on the user and technology. Future research efforts could include other, real-time scenarios and techniques. Additionally, further research should take into account environmental factors such as noise levels, communication styles, and temporal issues. By including such variables in future C2 research, a comprehensive evaluation of optimal prompting and collaboration techniques will be obtained, from both a user preference and performance standpoint.

6.0 References

1. Nelson, W. T., Bolia, R. S., Ericson, M.A., and McKinley, R. L. “Spatial Audio Displays for Speech Communications: A Comparison of Free Field and Virtual Acoustic Environments,” *Proceedings of the Human Factors and Ergonomics Society 43rd Annual Meeting*, pp. 1202–1205.
2. Gunn, D. V., Warm, J.S., Nelson, W. T., Bolia, R. S., Schumsky, D. A., and Corcoran, K. J., “Target Acquisition With UAVs: Vigilance Displays and Advanced Cuing Interfaces,” *Human Factors,* Vol. 47, No. 1, pp. 488-497, 2005.
3. Bolia, R. S., D’Angelo. W. R., and “Aurally aided visual search in three-dimensional space,” *Human Factors,* Vol. 41, No. 4, pp. 664-669, 1999.
4. Wickens. C. D., “Engineering psychology and human performance, 2nd Ed.,” New York: Harper Collins, 2002.
5. Parkes, A. M., and Coleman, N., “Route and guidance systems: A comparison of methods of presenting directional information to the driver,” *Proceedings from the Vehicle Navigation and Information Systems Conference,* Vol. 2, Issue, 20-23 pp. 61-70, 1990.
6. Woodworth, R. S. and Schlosberg, H., “Experimental Psychology,” New York: Holt, Rinehart, & Winston, 1965.
7. Knott, B. A., Bolia, R. S., Nelson, W. T., and Galster, S. M. “Effects of collaboration technology on the performance of tactical air battle management teams,” *Proceedings of the Symposium on Human Factors Issues in Network-Centric Warfare*, Sydney, Australia, 2006.
8. Clark, D. (2000). “Learning styles.” http://www.nwlink.com/donclark/hrd/learning/styles.html.
9. Fleming, N. D. and Mills, C., “Not Another Inventory, Rather a Catalyst for Reflection,” *To Improve the Academy*, Vol. 11, pp. 137-155, 1992.
10. Nielsen, J., & Mack, R. L. (Eds.) “Usability inspection methods.” New York, NY: John Wiley & Sons, 1994
11. Burgoon, J. K., Stoner, G. M., Bonito, J. A., & Dunbar, N. E., “*Trust and deception in mediated communication,*” Proceedings of the Hawaii International Conference in Systems Science, Kona, HI, 2003.
12. Jarvenpaa, S. L., and Leidner, D. E., “Communication and trust in global virtual teams,” *Organizational Science,* Vol. 10, No. 6, pp. 791-815, 1999.
13. Anderson, D.Z., “Correcting Readbacks,” *Aviation Safety*, Vol. 28, No. 3, pp. 3, 2008.
14. Streitenberger, K., “Handoffs in Care: Can We Make Them Safer?,” *Pediatric Clinics of North America*, Vol. 53, No. 6, pp. 1185-1195, 2006.

List of Acronyms

Acronym	Meaning
AFRL	Air Force Research Laboratory
ANOVA	Analysis of Variance
C2	Command and Control
DDD	Distributed Dynamic Decision-Making
DoD	Department of Defense
LOA	List of Acronyms
LSD	Large Screen Display
NASA	National Aeronautics and Space Administration
SSD	Small Screen Display
SO	Secondary Operator
TLX	Task Load Index
UAV	Uninhabited Air Vehicle
UDRI	University of Dayton Research Institute
USAF	United States Air Force